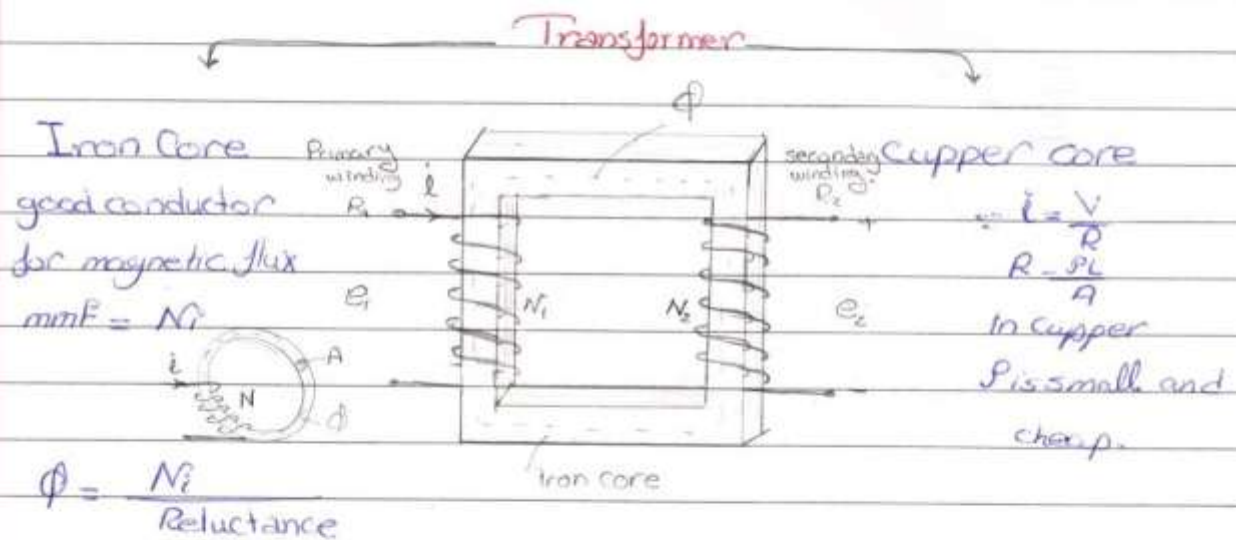


## Single-phase Transformer.

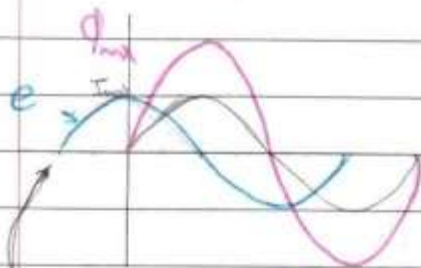
- To convert power from circuit to another at same frequency "primary ct. to secondary ct."
- Transformer is static Device. & we use it in AC only.



$$R_c = \frac{l}{\mu_0 \mu_r A}$$

$\mu_r$  = very high for iron  
 $\therefore R_c$  is very small  
 $R_{c \downarrow} \rightarrow \Phi \uparrow$

$$e = -N \frac{d\Phi}{dt}$$



$$i = I_{max} \sin \omega t$$

$$\Phi = \Phi_{max} \sin \omega t$$

$$e = -N \frac{d\Phi}{dt} = -N \frac{d(\Phi_{max} \sin \omega t)}{dt} = N \Phi_{max} \omega \cos \omega t$$

$E_{max}$

$$E_{max} = N \Phi_{max} \omega$$

$$E_{rms} = \frac{N \Phi_{max} \omega}{\sqrt{2}}$$

$$e_{rms} = \frac{N \Phi_m \omega}{\sqrt{2}} = \frac{2\pi f N \Phi_{max}}{\sqrt{2}} = \sqrt{2} \pi f N \Phi_{max}$$

$$e_{rms} = 4.44 f N \Phi_{max} \quad \#$$

$$E_1 = 4.44 f N_1 \Phi_{max}$$

$$E_2 = 4.44 f N_2 \Phi_{max}$$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \#$$

✓  $N_1 > N_2$  step down Transf.

✓  $N_1 < N_2$  step up Transf.

$$R_1 = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad \#$$

types of load.	over load	زيادة على الحمل المسموح
	full load	الحمل المسموح المسموح
	half load	نصف الحمل
	low load	محملي الحمل المنخفض

Ex: 10 K VA , 250/125 V Transf.

$$\text{Sol: } V_{N1} = 250$$

$$V_{N2} = 125$$

$$10 \times 10^3 = V_1 I_{N1} = V_2 I_{N2}$$

$$= 250 \times I_{N1} = 125 I_{N2}$$

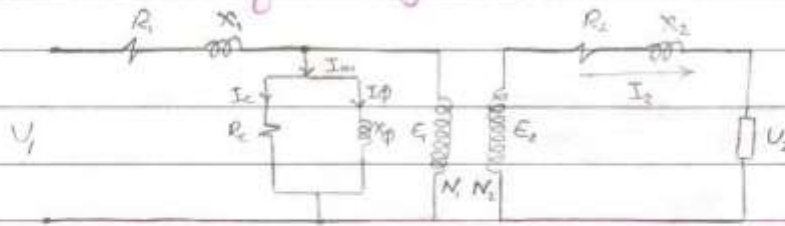
$$I_{N1} = 40 \text{ A}$$

$$I_{N2} = 80 \text{ A}$$

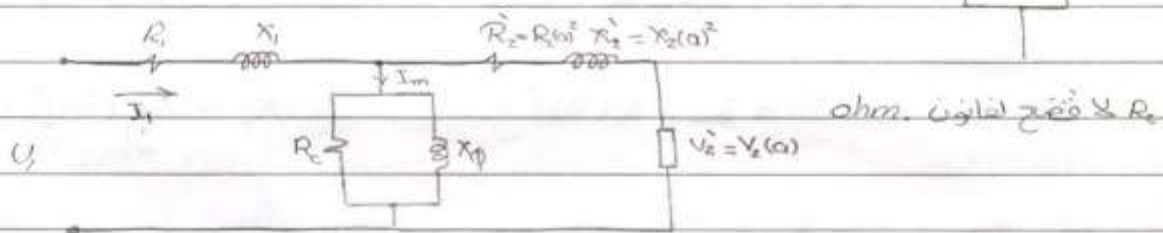
Notes: To measure AC  $\rightarrow$  RMS

DC  $\rightarrow$  average

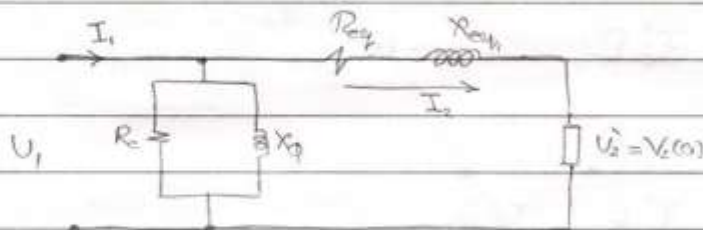
## Equivalent circuit of a transformer



## a. Referred to primary side



## Exact Equivalent Circuit



## Approximate Equivalent circuit

$$R_{eq} = R_1 + R_2' = R_1 + R_2/a^2$$

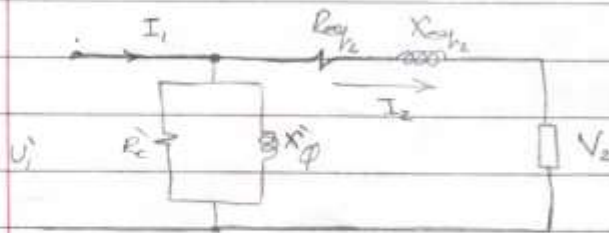
$$X_{eq} = X_1 + X_2' = X_1 + X_2/a^2$$

$$V_2' = V_2/a$$

$$I_2' = I_2/a$$

$$\text{where } a = \frac{N_1}{N_2}$$

Referred to secondary side.



referred jaiwal jai  
secondary side primary side  
Gives total losses

$$a = \frac{N_1}{N_2}$$

$$V'_1 = V_1 \div a$$

$$R_{eq} = R_2 + R'_1 = R_2 + R_1 (V_1/V_2)^2$$

$$R'_e = R_1 (V_1/V_2)^2$$

$$X_{eq} = X_2 + X'_1 = X_2 + X_1 (V_1/V_2)^2$$

$$X'_q = X_q (V_1/V_2)^2$$

Losses

1. Iron losses

$$P_i = I_e^2 R_e \quad \text{"Fixed"}$$

iron losses

2. Copper losses:

$$P_c = I_1^2 R_1 + I_2^2 R_2$$

$$= I_1^2 R_{eq} = I_2^2 R_{eq} \quad \text{"Variable"}$$

$$\text{Total loss} = P_i + P_c$$

Power factor:

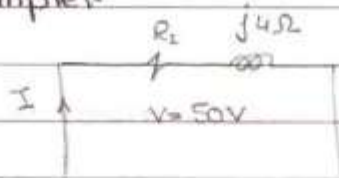
1. unity power factor  $Z_L = Z_R \Rightarrow V_e \parallel I$

2. lagging power factor:  $Z_L = R + jX_L \Rightarrow V_e \angle \phi, I$

3. leading power factor:  $Z_L = R - jX_L \Rightarrow V_e \angle \phi, I$

$$PF = \cos \phi$$

exampler.



Soln

$$Z_1 = 3 + j4 = 5 \angle 53.13^\circ$$

$$I = \frac{V}{Z_1} = \frac{50 \angle 0^\circ}{5 \angle 53.13^\circ} = 10 \angle -53.13^\circ$$

$$P.f. = \cos 53.13 = 0.6 \text{ lagging}$$

$$S = V.I = 50 \times 10 = 500 \text{ VA}$$

$$P = V.I \cos \phi = 50 \times 10 \times 0.6 = 300 \text{ W}$$

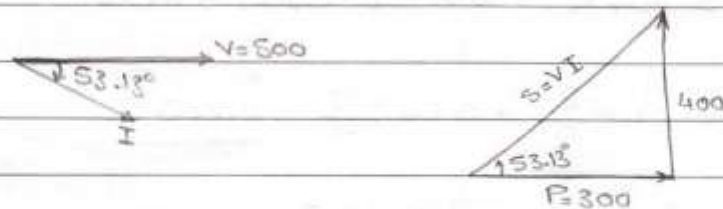
$$V.I \sin \phi = 50 \times 10 \times 0.8 = 400 \text{ VAR}$$

$$\cos^2 x + \sin^2 x = 1$$

$$\sin x = \sqrt{1 - \cos^2 x}$$

$$= \sqrt{1 - (0.6)^2}$$

$$= 0.8$$





Exampler-

A 5 KVA, 500/250 V single phase transformer has the following parameter.

$$R_1 = 1/2 \Omega \quad X_1 = 0.6 \Omega \quad R_2 = 0.1 \Omega \quad X_2 = 0.15 \Omega$$
$$R_c = 5 K\Omega \quad X_m = 500 \Omega$$

Required-

- 1)  $R_{eq}$  &  $R_{eq_h}$
- 2) total losses at half load
- 3) copper losses at full load & Iron losses
- 4) efficiency at Full load & half load at 0.8 P.F. lagging.

Sol:-

$$a = \frac{N_1}{N_2} = \frac{500}{250} = 2$$

$$(1) R_{eq_h} = R_1 + R_2' = 1/2 + (0.1)(2)^2 = 0.9 \Omega$$
$$X_{eq_h} = X_1 + X_2' = 0.6 + (0.15)(2)^2 = 1.2 \Omega$$

$$R_{eq_2} = R_2 + \frac{R_1}{a^2} = 0.1 + \frac{0.5}{4} = 0.225 \Omega$$

$$X_{eq_2} = X_2 + \frac{X_1}{a^2} = 0.15 + \frac{0.6}{4} = 0.3 \Omega$$

$$\text{N.B. } R_{eq_h} = R_{eq_2} (a)^2$$

(2)

$$5 \text{ KVA} = 5000 = 500 I_{N1} = 250 I_{N2}$$

$$I_{N1} = 10 \text{ A}$$

$$I_{N2} = 20 \text{ A}$$

$$P_{cu \text{ full}} = I_{N1}^2 R_1 + I_{N2}^2 R_2 = (10)^2 (0.5) + (20)^2 (0.1) = 50 + 40 = 90 \text{ W}$$

or

$$P_{cu \text{ full}} = I_{N2}^2 R_{eq_2} = (20)^2 (0.225) = 90 \text{ W}$$

$$P_{\text{half load}} = P_{\text{full load}} \left( \frac{1}{2} \right)^2 = 22.5 \text{ W}$$

$$P_i = I_c^2 R_c$$

$$\text{where } I_c = \frac{V}{R_c} = \frac{500}{5000} = 0.1 \text{ A}$$

$$P_{\text{iron}} = (0.1)^2 \times 5000 = 50 \text{ watt}$$

$$\text{loss at Full load} = P_i + P_{cu} = 50 + 90 = 140 \text{ w}$$

at 50% load

$$\text{loss} = 50 + 22.5 = 72.5 \text{ w}$$

iron loss is constant

High PF is better

$$\eta = \frac{P_{\text{out}} + P_f}{P_{\text{out}} + \text{losses}}$$

$$\eta_{FL} = \frac{5000 \times 0.8}{5000 \times 0.8 + 50 + 90} = 0.966 \%$$

$$= 96.6 \%$$

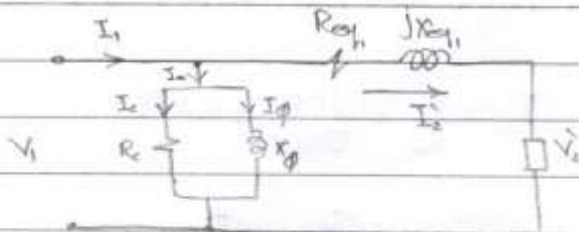
$$\eta_{HL} = \frac{\frac{1}{2}(5000)(0.8)}{\frac{1}{2}(5000)(0.8) + 50 + 90(0.5)^2} = \frac{2000}{2072.5} = 96.5 \%$$

$$\eta_{x\text{-load}} = \frac{x(\text{kVA})(\text{P.F.})}{x(\text{kVA})(\text{P.F.}) + P_{\text{iron}} + P_{cu}(\text{Full load})(x^2)}$$

$$0 < x < 1$$

$$X_m = \sqrt{\frac{P_i}{P_{cu \text{ Full}}}}$$

←  $X_m$  is value ??



عابرين يجب ان Parameter الى  $R_{eq}$  و  $X_{eq}$  و  $R_1$  &  $X_1$

## Parameters

Iron part

$R_1 + X_1$

open circuit test

O.C.T

Copper part

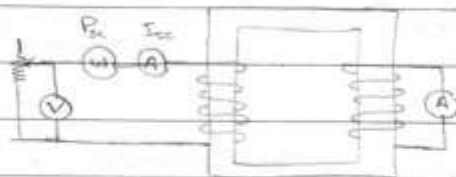
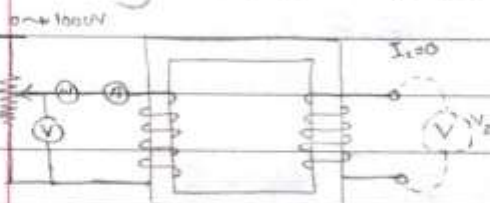
$R_{eq} + X_{eq}$

short circuit test

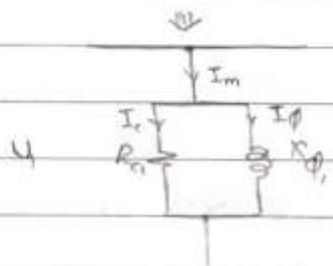
S.C.T

(HVS) high voltage side → Primary

Secondary (L.V) low voltage side



$V_1$	$I_0$	$P_0$	$V_2$
50			50
100			100
150			150
200			200



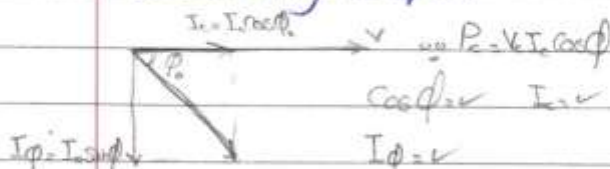
sec. جانب  $P_0$  O.C.T (HVS):

Voltage open 500V, 1A, 120W

من ما يكون (HVS) في 500V

Power transformer

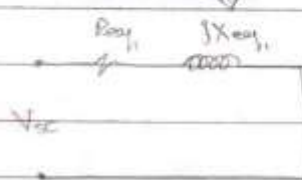
secondary is open



بفضل انقل الى  $P_0 = V_1 I_0 \cos \phi$

الجهد 250 بدل 500 وبكدة التيار عند Primary

حرفه فبكذا بفضل يكون عند sec.

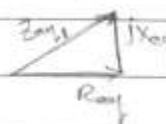


$$P_{sc} = I_{sc}^2 R_{eq}$$

$$R_{eq} = \frac{P_{sc}}{I_{sc}^2}$$

$$V_{sc} = I_{sc} Z_{eq}$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$



هذا اهل الدائرة بناعة لا iron ولا 500V

كان حاتفه تيار 1A وفي الدائرة دي الجهد 500V

بفضل التيار 1A فبكذا اهل الدائرة



Example: 10 KVA, 500/250 V, single phase transformer has a following test data:-

open circuit test (O.C.T) (H.V.S), 500V, 1A, 200 watt

short circuit test (S.C.T) (L.V.S), 25V, 40A, 600 watt

(1) obtain the parameter of this transformer referred to primary & referred to secondary side.

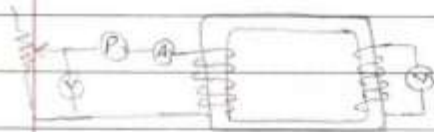
(2) obtain the max. efficiency at 0.8 P.f. lagging.

Soln-

(a)

**O.C.T (H.V.S)**

500V, 1A, 200 watt



$$P_o = V_o I_o \cos \phi$$

$$\cos \phi = \frac{200}{(500)(1)} = 0.4$$

$$\sin \phi = 0.96$$

$$I_c = I_o \cos \phi = 0.4 \text{ A}$$

$$I_\phi = I_o \sin \phi = 0.96 \text{ A}$$

$$R_o = \frac{V_o}{I_c} = \frac{500}{0.4} = 1250 \Omega$$

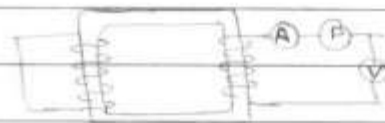
$$X_\phi = \frac{V_o}{I_\phi} = \frac{500}{0.96} = 545.5 \Omega$$

$$R_e = \frac{R_o}{a^2} = \frac{1250}{4} = 312.5 \Omega$$

$$X_\phi = \frac{X_\phi}{a^2} = \frac{545.5}{4} = 136.4 \Omega$$

**S.C.T (L.V.S)**

25V, 40A, 600 watt



$$P_{sc} = I_{sc}^2 R_{eq_h}$$

$$R_{eq_h} = \frac{600}{(40)^2} = 0.375 \Omega$$

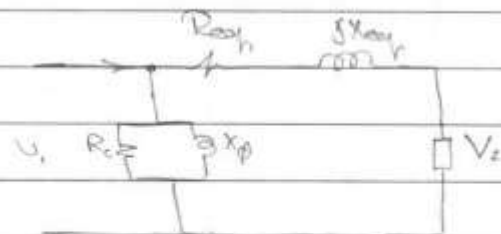
$$V_{sc} = I_{sc} Z$$

$$Z = \frac{V_{sc}}{I_{sc}} = \frac{25}{40} = 0.625 \Omega$$

$$X_{eq_h} = \sqrt{Z^2 - R_{eq_h}^2} = 0.5 \Omega$$

$$R_{eq_h} = R_{eq_h} (a^2) = 4 \times 0.375 = 1.5 \Omega$$

$$X_{eq_h} = X_{eq_h} a^2 = 2 \Omega$$



Primary referred to secondary side

Primary referred to secondary side

referred to secondary

(b)

$$P_{in} = 200 \text{ W} \quad \text{"open ct."}$$

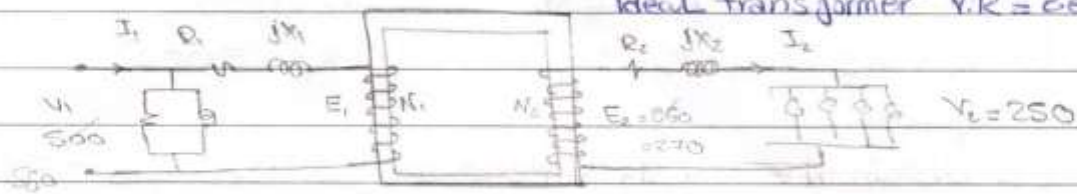
$$\text{or } I_e^2 R_c = 200 \text{ W}$$

$$P_{cu(FL)} = I_{N_1}^2 R_{eq1} = I_{N_2}^2 R_{eq2} \\ = (20)^2 (1.5) = (40)^2 (0.375) = 600 \text{ W}$$

Short circuit power (Circuit) is the power dissipated in the  
ct. test.

= The change in the secondary voltage from no load  
**Voltage Regulation** to full load for the same primary voltage  
 \* The voltage regulation is like the figure of merit of a transformer.

Ideal transformer V.R = zero.



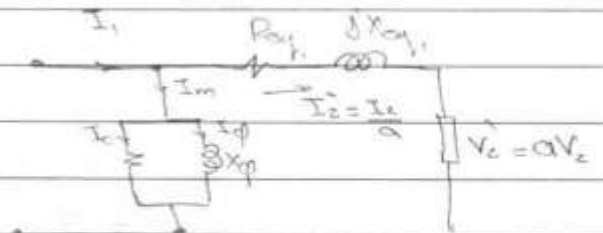
$$E_2 = I_2 Z_2 + V_2$$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = a$$

$$* V.R = \frac{V_1 - V_1'}{V_2} = \frac{580 - 500}{500} = \frac{80}{500} = 16\%$$

$$V.R = V_1 - V_2$$

$$V.R\% = \frac{V_1 - V_1'}{V_2} \times 100 =$$

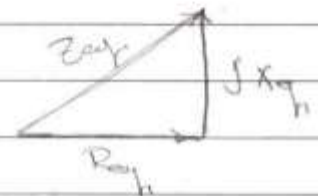


$$I_1 = I_2 \angle \phi_e + \frac{V_1}{R_e} - j \frac{V_1}{X_\phi}$$

$$= a + jb = \sqrt{a^2 + b^2} \angle \tan^{-1} \frac{b}{a}$$

$$V_1 = V_2 \angle 0 + I_2' \angle \phi_2 Z_{eq1} \angle \theta$$

$$= A + jB$$



$$V_1 = \sqrt{A^2 + B^2} \angle \tan^{-1} B/A = \phi_1$$

$$\text{where } |Z_{eq}| = \sqrt{R_{eq}^2 + X_{\phi}^2} \angle \tan^{-1} X_{\phi}/R_{eq}$$

$$P_m = V_1 I_1 \cos \phi_1$$

$$\text{where } \phi_1 = \alpha + \beta$$

$$P_{out} = V_2 I_2 \cos \phi_e$$

ex8-

Example: 10 kVA, 500/250 V, single phase transformer has the following parameter.

$$R_1 = 1.2 \Omega, X_1 = 1.6 \Omega$$

$$R_2 = 0.3 \Omega, X_2 = 0.4 \Omega$$

$$R_c = 1200 \Omega$$

$$X_m = 500 \Omega$$

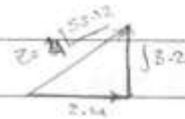
Required:-

- (V<sub>1</sub>) 1. Obtain the supply voltage at full load and 0.8 pf lagging
- (I<sub>1</sub>) 2. obtain the input current at this case.
- $\frac{(V_1 - V_2)}{V_1}$  3. obtain the voltage regulation.

Sol:-

$$R_{eq} = 1.2 + 0.3(2) = 2.4 \Omega$$

$$X_{eq} = 1.6 + (0.4)(4) = 3.2 \Omega$$



$$V_1 = V_2 + I_2 R_{eq} + j I_2 X_{eq}$$

$$\overset{(250)(40)}{\underset{2}{\rightarrow}} = 500 \angle 0 + (20 \angle -36.87^\circ)(4 \angle 53.13^\circ)$$

$$= 500 \angle 0 + 80 \angle 16.26^\circ$$

$$= 500 + 80 [0.96 + j0.28]$$

$$= 500 + 76.8 + j22.4$$

$$= 576.8 + j22.4 = 577.23 \angle 2.22^\circ$$

$$V.R = V_1 - V_2 = 77.23 V = \frac{77.23}{500} \times 100 = 15.44 \%$$

$$I_1 = I_2 + I_c + I_m$$

$$= 20 \angle -36.87^\circ + \frac{577.23}{1200} \angle -90^\circ + j \frac{577.23}{500}$$

$$= 16 \angle -j12 + 0.48 \angle -90^\circ + j1.175$$

$$= 16.48 \angle -j13.15 = 21.08 \angle -38.58^\circ$$

$$P_i = V_1 I_1 \cos \phi = 577.23 \times 21.08 \times \cos(38.58^\circ + 2.22^\circ) \times 0.8$$
$$= 9211.1 \text{ W}$$

$$P_{out} = V_2 I_2 \cos \phi = 250 \times 40 \times 0.8 = 8000 \text{ watt}$$



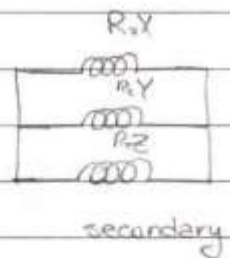
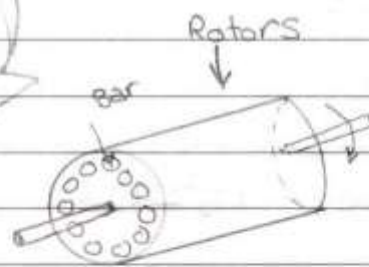
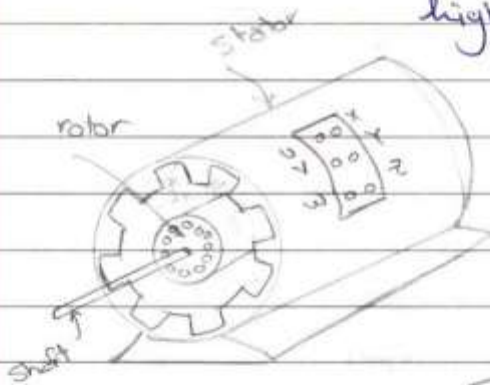
## Chapter II

### Three phase Induction Motors.

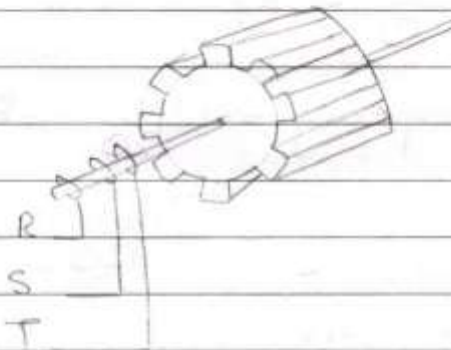
Stator + Rotor

(wound Rotor)  
high power

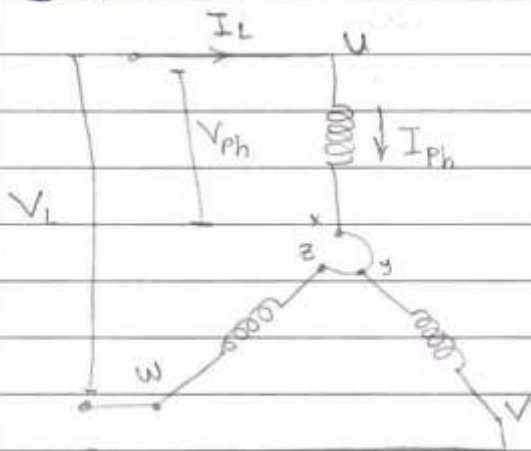
(squirrel cage Rotor)  
low power



سجّل قفّاز كئبر  
squirrel cage



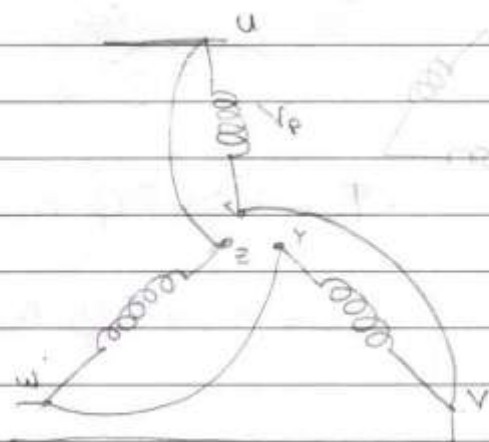
Star



$$V_L = \sqrt{3} V_{ph}$$

$$I_L = I_{ph}$$

Delta



$$V_L = V_{ph}$$

$$I_L = \sqrt{3} I_{ph}$$

$$\text{Let slot } (S) = 12$$

$$\text{Poles } (P) = 2$$

$$\text{Phases } (m) = 3$$

$$* n_s : \text{Synchronous Speed} = \frac{120f}{P} \text{ rpm}$$

$$= \frac{120 \times 50}{2} = 3000 \text{ rpm}$$

$$\text{emf} = N \frac{d\phi}{dt}$$



$$F = Bli$$

$$* \text{Slip-Speed} = n_s - n_r \text{ rpm}$$

$$* S = \frac{n_s - n_r}{n_s} \quad 0 \leq S \leq 1$$

$$\text{at starting } S = 1 \text{ and } n_r = 0$$

$$* \text{Stator Frequency} = \frac{P n_s}{120} = f_1$$

$$* \text{Rotor Frequency} = \frac{P(n_s - n_r)}{120} = f_2$$

$$* f_2 = \frac{P(n_s - n_r)}{120} \times \frac{n_s}{n_s} = \frac{P n_s}{120} \cdot \frac{n_s - n_r}{n_s}$$

$$f_2 = f_1 S$$

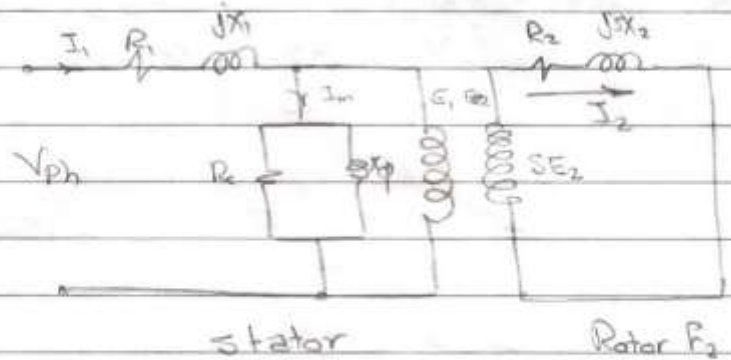
$$E_1 = 4.44 f_1 \phi N_{ph}$$

$$E_2 = 4.44 f_2 \phi N_{PL} \approx S E_1$$

## Equivalent Circuit

$$I_2 = \frac{SE_2}{R_2 + jSX_2}$$

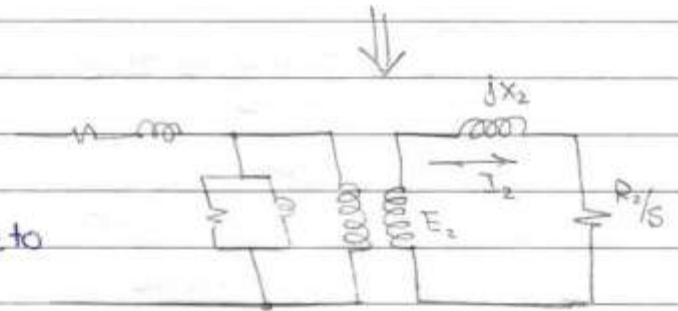
$$= \frac{E_2}{\frac{R_2}{S} + jX_2}$$



$$\frac{R_2}{S} = R_2 + \frac{R_2(1-S)}{S}$$

$$= R_c + R_m$$

↓ resistance due to load.



## Examples-

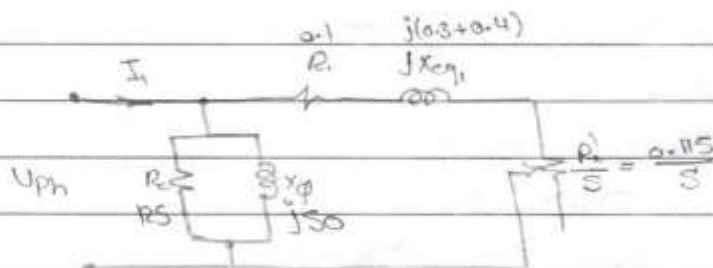
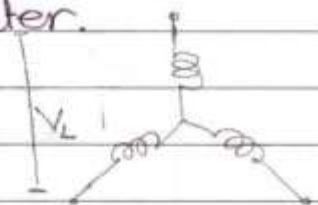
A 433V star connection four Pole 50Hz, 1425 rpm

Three phase induction motor has the following Parameter

$R_1 = 0.1 \Omega$ ,  $X_1 = 0.3 \Omega$ ,  $R_2' = 0.115 \Omega$ ,  $X_2' = 0.4 \Omega$ ,  $R_c = 125 \Omega$   
 $X_m = 50 \Omega$ , obtain

- 1- The slip at full load
- 2- The input current and input power factor.
- 3- The full load efficiency if the fractional losses = 2.3
- 4- The starting Torque in newton meter.

all 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000



\* لوصل الميكنة الى  $P_c$  في  $\Delta$  الية  $\Delta$   $\infty$

\* دلتا الى  $V_L$  التي يوصلها هو  $V_L$  ولولفان  $\Delta$  في  $P_{ph}$  هو  $P_{ph}$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{433}{\sqrt{3}} = 250V$$

$$n_f = 1425 \text{ rpm}$$

$$n_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$(a) S_{sl} = \frac{n_s - n_f}{n_s} = \frac{1500 - 1425}{1500} = 0.05 \quad P_r = 5\%$$

$$\frac{R'_2}{S} = \frac{0.115}{0.05} = 2.3 \Omega$$

$$(b) I'_2 = \frac{V_{ph}}{(0.1 + 2.3) + j0.7} = \frac{250 \angle 0^\circ}{2.4 + j0.7} = \frac{250 \angle 0^\circ}{2.2 \angle 16.26^\circ}$$

$$= 100 \angle -16.26^\circ \text{ A} = 96 - j28$$

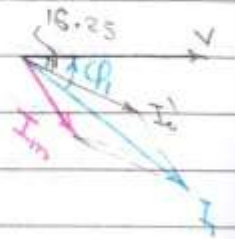
$$I_m = I_c + I_\phi = \frac{250}{125} - j \frac{250}{50} = 2 - j5$$

$$I_1 = I_m + I'_2 = 98 - j33 = 103.4 \angle -18.6^\circ \text{ A}$$

دلتا الى  $P_{ph}$

$I_1$  الى  $P_{ph}$

$$P_f = \cos \phi = \cos 18.6 = 0.9477 \text{ lagging}$$



(c)

$$P_{in} = P_{out} + P_g = 3 I_1^2 \frac{R'_2}{S}$$

$$P_{in} = 3(250)(103.4)(0.9477) = 73495 \text{ W}$$

$$P_{out} = P_{in} - P_g$$

$$P_g = 3 I_1^2 \frac{R'_2}{S} = 3(100)^2(2.3) = 69000 \text{ W}$$

$$P_m = P_g(1 - S) = 69000 \times 0.95 = 65550 \text{ W}$$

$$P_{out} = P_m - P_f = 65550 - 2300 = 63250 \text{ W}$$



$$P_{out}|_{hp} = \frac{63250}{746} = 84.7 \text{ hp}$$

hp =  $\frac{W}{746}$   
 $\frac{63250}{746}$

$$\eta = \frac{63250}{73495} = 86\%$$

(d)

$$T_{st} = \frac{P_{st}}{\omega_s} = \frac{69000}{2\pi \times \frac{1500}{60}} = \frac{69000}{50\pi} = 439.5 \text{ N.m}$$

على  $\omega_s$  (Torque)  $\omega_s$   
 -  $\omega_s$  (S)  $\omega_s$  (S)  $\omega_s$

→ Starting torque at  $s=1$  →  $T_{st}$  starting torque

$$I_s' = \frac{250}{(0.112 + j0.1)(0.215 + j0.7)} = 341.4$$

التيار  $I_s'$  start

$$P_g = 3(341.4)^2 0.115 = 40212 \text{ W}$$

$$T_{st} = \frac{P_{gst}}{\omega_s} = \frac{40212}{50\pi} = 256 \text{ N.m}$$

$$\text{ratio of } T_{st} \text{ to } T_{st} = \frac{256}{439.5} = 0.58 = 58\%$$

بترجیح الی قبل (ا) (ب)

$$n_s = \frac{120f}{P} \text{ rpm}$$

$$s = \frac{n_s - n_r}{n_s} \text{ pu "Per unit"} \quad n_s > n_r \text{ داغیا اور } n_s < n_r \text{ دالیا}$$

\* at starting ( $n_r = 0$ )  $\Rightarrow s = 1$

\* at no load  $n_r \rightarrow n_s \Rightarrow s \rightarrow 0 \Rightarrow 0 < s < 1$

$$s_{FL} = [0.03 \rightarrow 0.06]$$

$$\text{eg } \frac{R_2}{s} > R_2 \quad \text{لانہ اور } s \text{ کم اقل من 1}$$

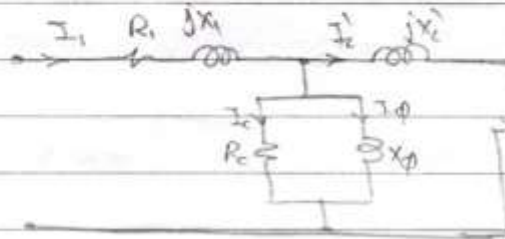
$$\frac{R_2}{s} = R_2 + R_m$$

$$\text{or } \frac{R_2}{s} = R_2 + \frac{R_2(1-s)}{s}$$

علت دی کدہ لانہ نا اعلیٰ

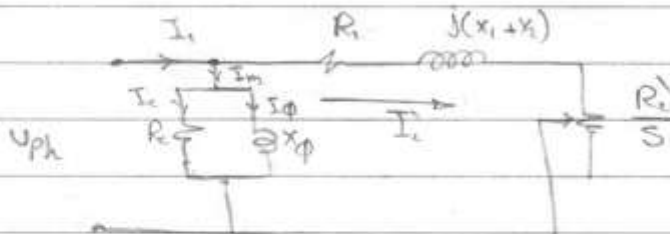
$R_2$  داغیا نا بیلہ وار load

$R_m$  بیلیٹر فیلچرک



Exact E. Circuit

\* Approximate Elec. circuit



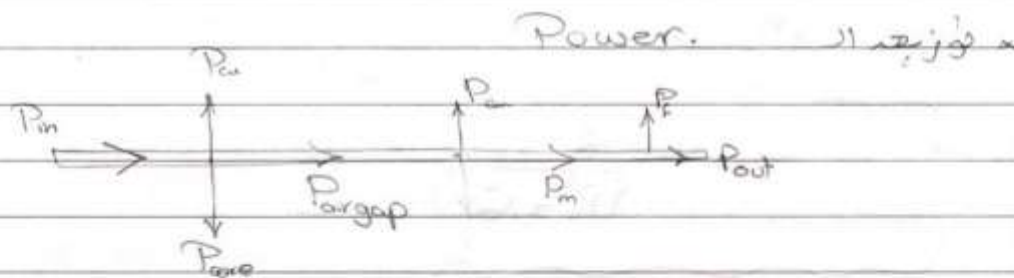
$$I_m = I_c + I_\phi = \frac{V_{ph}}{R_c} - j \frac{V_{ph}}{X_\phi}$$

$$I_2' = \frac{V_{ph} L_c}{(R_1 + \frac{R_1'}{s}) + jX_{eq}} = \frac{V_{ph} L_c}{\sqrt{(R_1 + \frac{R_1'}{s})^2 + X_{eq}^2}} \angle -\tan^{-1} \frac{X_{eq}}{R_1 + R_1'}$$

$$I_1 = I_m + I_2' = |I_1| \angle -\phi_1$$

$$P_{in} = 3 V_{ph} I_1 \cos \phi_1$$

3 phase input



$$P_{in} = 3 V_{ph} I_1 \cos \phi_1$$

stator losses

$$P_{cu} = 3 I_1^2 R_1$$

$$+ P_{core} = 3 I_c^2 R_c$$

Air gap power

$$P_g = T_s \omega_s$$

$$= 3 I_2'^2 \frac{R_2'}{s}$$

$$P_{core} = 3 I_2'^2 R_c'$$

$$= s P_g$$

$$P_m = 3 I_2'^2 R_m$$

$$= P_g (1-s)$$

Note: losses of iron in rotor is very small

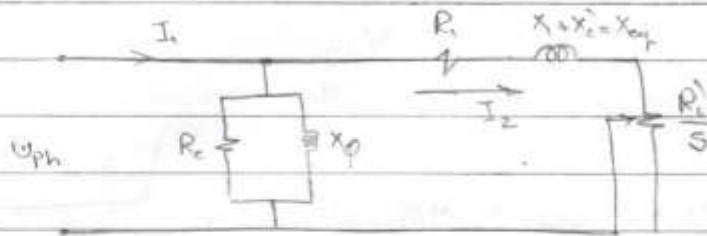
$$\omega_m = \frac{2\pi n_r}{60} \quad P_{elec} = V \cdot I$$

$$P_{fr}$$

Given

$$P_{out} = T_{sh} \omega$$

$$\omega_s = \frac{2\pi n_s}{60} \quad P_{Mech} = T \cdot \omega$$



$$\begin{aligned} T_d &= \frac{P_g}{\omega_s} = \frac{3 I_2^2 R_2/s}{\omega_s} = \frac{3 R_2'}{\omega_s S} I_2^2 \\ &= \frac{3 R_2'}{\omega_s S} \frac{V_{ph}^2}{(R_1 + \frac{R_2'}{S})^2 + X_{eq}^2} \end{aligned}$$

To Get Max. \$S\$

$$\frac{dT_d}{dS} = 0$$

$$\therefore S_{max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}} \quad \# \quad \text{dep}$$

$$T_{max} = \frac{3 V_{ph}^2}{3 \omega_s [R_1 + \sqrt{R_1^2 + X_{eq}^2}]}$$

\$\hookrightarrow\$ \$R\_2\$ is directly

\* assume \$R\_1=0\$ "stator"

$$\therefore T_d = \frac{3}{\omega_s} \frac{V_{ph}^2}{(\frac{R_2'}{S})^2 + X_{eq}^2} \frac{R_2'}{S} = K S$$

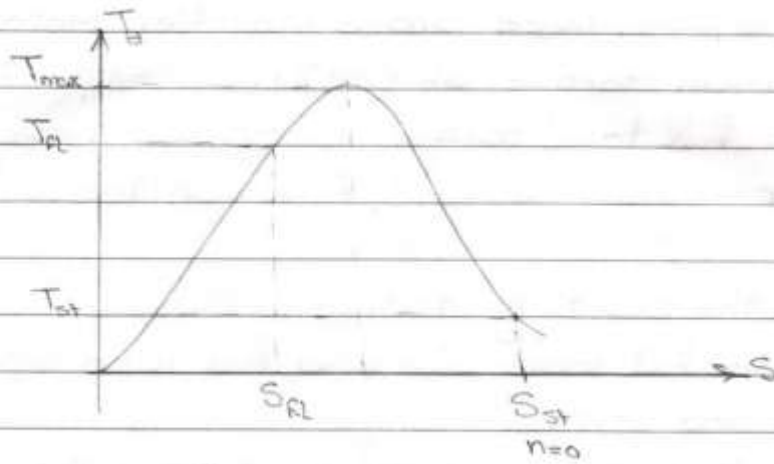
$$S_{max} = \frac{R_2'}{X_{eq}} \quad \#$$

$$T_{max} = \frac{3 V_{ph}^2}{2 \omega_s X_{eq}} \quad \#$$

$$\frac{T}{T_{max}} = \frac{2 \frac{R_2'}{S} X_{eq}}{(\frac{R_2'}{S})^2 + (X_{eq})^2} = \frac{2}{\frac{R_2'}{S X_{eq}} + \frac{S X_{eq}}{R_2'}} = \frac{2}{\frac{S_{max}}{S} + \frac{S}{S_{max}}}$$

$$T_F = \frac{2 T_{max}}{\frac{S_{max}}{S_F} + \frac{S_F}{S_{max}}} \quad \text{Given } T_{max}, S_{max}$$





(TIS Curve)

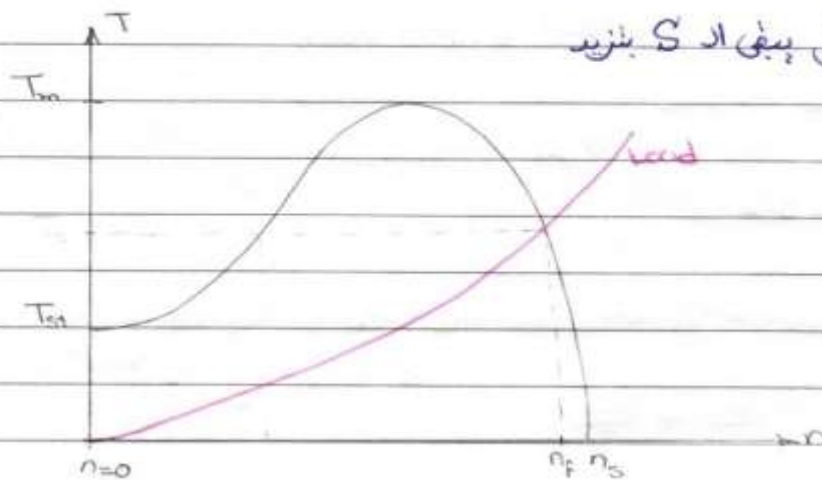
$$S = \frac{n_s - n}{n_s}$$

$$S_n = n - n$$

$$n = n_s - 5n_s$$

$$n = n_s(1 - S)$$

کلی  $L$  و  $n$  با نقل بهی از  $S$  بنزید



$s=1$  (Tln curve)  $s=0$

(Tln curve)

أجزاء زيادة

### Example 3.

A 50 Hz, 6 pole, three phase induction Motor has a maximum torque of 200% at a slip of 0.2 if the Full load torque is 50 N.m. neglect the stator resistance and Friction losses

1. Obtain the starting torque in N.m
2. Obtain the Full load slip and Full load speed
3. The speed at Max. torque
4. Obtain the added resistance to the rotor to obtain the max torque at starting at the same torque
5. Obtain the Radd to change the speed at full load to 900 R.P.M

Sol:

$$n_s = \frac{120f}{P} = \frac{120(50)}{6} = 1000 \text{ rpm}$$

$$T_{max} = 200\% = 2 \text{ pu}$$

$$S_{max} = 0.2$$

$$T_{FL} = 50 \text{ N.m}$$

$$(a) \quad T_s = \frac{2 T_{max}}{\frac{S}{S_{max}} + \frac{S_{max}}{S}} \quad \text{at starting } S=1$$

$$T_s = \frac{2(2)}{\frac{1}{0.2} + \frac{0.2}{1}} = \frac{4}{5.2} = 0.77 \text{ Pu}$$

(b) Full load at  $S_f$

$$T_{FL} = \frac{2 T_{max}}{\frac{S_f}{S_{max}} + \frac{S_{max}}{S_f}}$$

Torque in full load is 1 pu

$$1 = \frac{2(2)}{\frac{S_f}{0.2} + \frac{0.2}{S_f}} \Rightarrow \frac{S_f}{0.2} + \frac{0.2}{S_f} = 4$$

$$S_f^2 + 0.04 = 0.8 S_f$$

$$S_f^2 - 0.8 S_f + 0.04 = 0$$

$$S_f = 0.746$$

refused

$$S_f = 0.053$$

Accept

$S_{max}$  (من قبل  $S_f$  الـ  $S_f$ )

$$S_{max} > S_f$$

$$\therefore S_f = 0.053 \quad P_u = 5.3 \%$$

$$\begin{aligned} n_f &= n_s(1 - S_f) = 1000(1 - 0.053) \\ &= 947 \text{ rpm} \end{aligned}$$

$$(6) \quad n_{max} = n_s(1 - S_{min})$$

$$= 1000(1 - 0.2) = 800 \text{ rpm.}$$

$$R_{add} = \frac{S_2 - S_1}{S_1} R_2$$

هو

(d) to obtain max. torque at the start of the same torque  
( $S_1$ ) ( $S_2$ )

$$\therefore S_1 = S_{max}$$

$$S_2 = S_{st} = 1$$

$$\therefore R_{add} = \frac{1 - 0.2}{0.2} R_2 = 4 R_2$$

(e) to change speed at full load to 900 rpm

$$S = \frac{n_s - n_r}{n_s}$$

$$S_{f1} = 0.053 \text{ calculated in (b)}$$

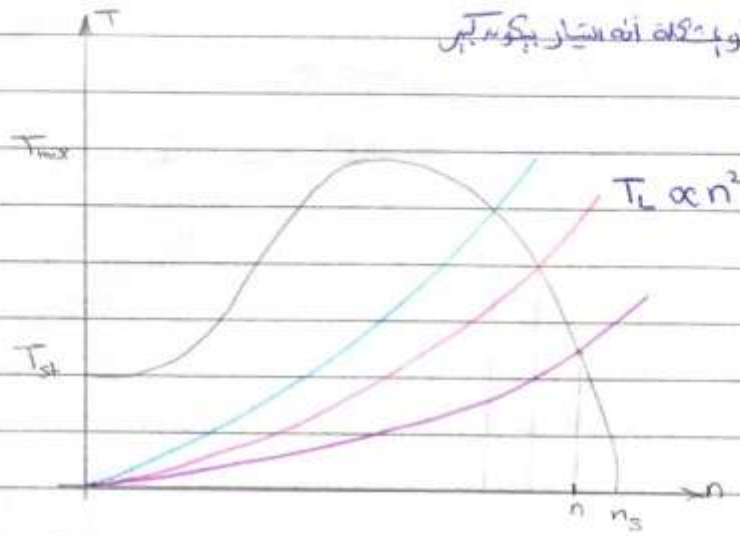
$$S_{f_{900}} = \frac{n_s - 900}{n_s}$$

$$S_{f_{900}} = \frac{1000 - 900}{1000} = 0.1$$

$$\therefore R_{add} = \frac{0.1 - 0.053}{0.053} R_2 = 0.88 R_2 \approx R_2$$

Note :-

پہچانی Motor کی آکر  
اد  $T$  و  $n$  کے ساتھ ان کے تعلق کو دیکھیں



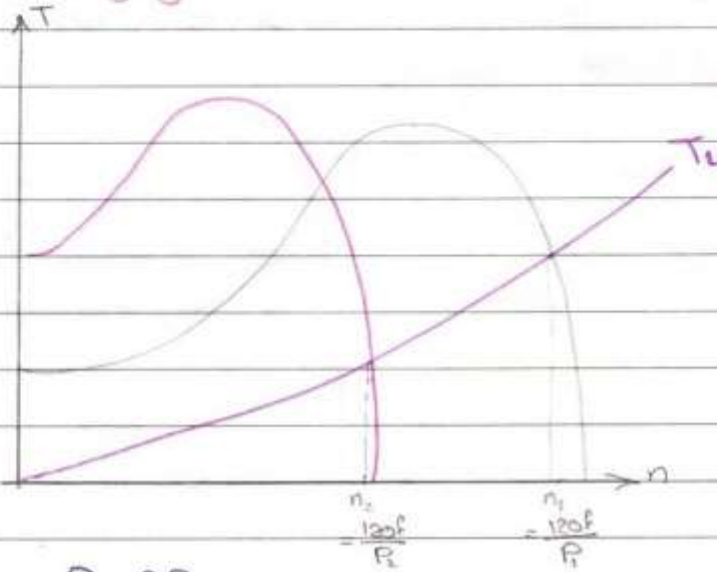
کل LL آلودہ اٹل پر روتہ نقل

#### \* Speed control of induction Motor

- 1- Pole changing " squirrel case "
- 2- Line Frequency control
- 3- line voltage control
- 4- Rotor resistance control " wound Rotor "

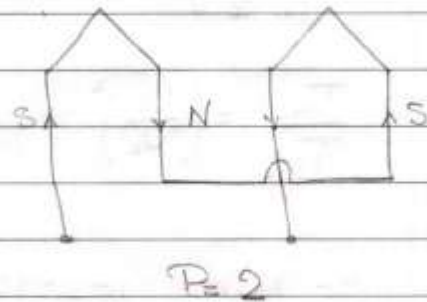
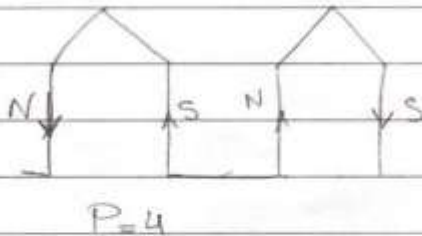


## 1- Pole changing.

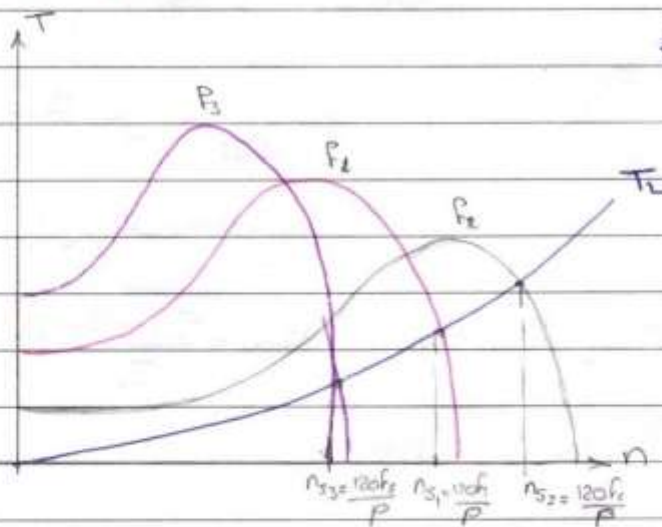


where  $P_2 = 2P_1$

لفصل الخطاب يكون  
connection (مفتاح)



## 2. Frequency control



$$P_2 > P_1 > P_3$$

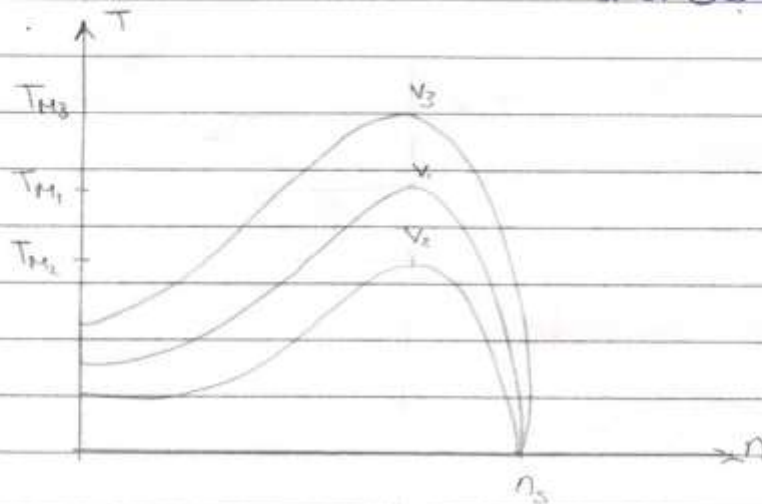
$$T_{max} = \frac{3V_{ph}^2}{2\omega_s X_{eq}} \propto \left(\frac{V}{f}\right)^2$$

$$T_m \propto 1/f^2$$

$$\frac{T_{m1}}{T_{m2}} = \left(\frac{f_2}{f_1}\right)^2$$

### 3] line voltage control

تقسیم الکتریسیته  
در شبکه ای برای ال  $T_{st}$

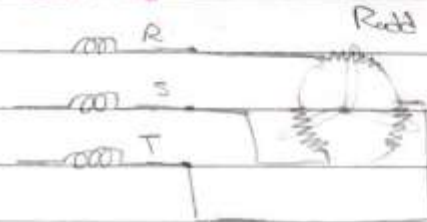
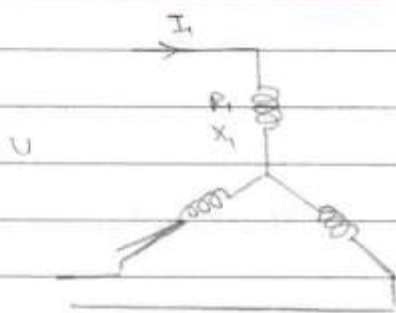


$$V_3 > V_1 > V_2$$

$$T_m \propto V^2$$

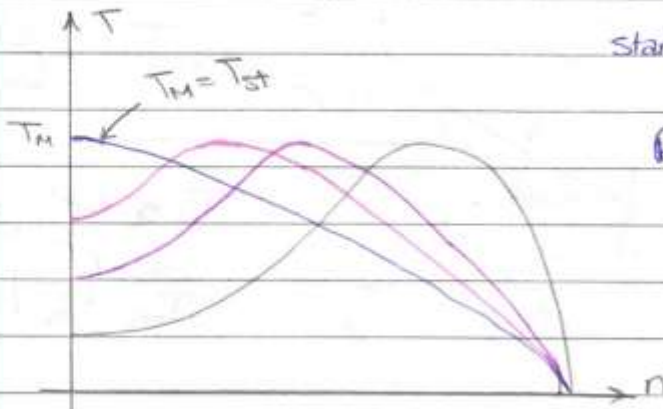
$$\frac{T_{M1}}{T_{M2}} = \left(\frac{V_1}{V_2}\right)^2$$

### 4- Rotor resistance control



Starting current ال  $R_{add}$

ولتور ال starting torque



$$R_{add} = \frac{s_2 - s_1}{s_1} \cdot R_2$$

A  $\frac{P}{2}$  hp power, 3 phase, 440 V, 4 pole, 60 Hz wound rotor induction motor developed its rated torque at a speed of 1746 rpm. The max Torque is 200% and the rotor resistance = 0.152, neglect rotational losses and the stator resistance.

- Calc. 1- The slip at Max torque & the speed.  
 2- The starting torque in N.m  
 3- Rotor to produce a Max Torque at starting.

sol:  $P = 4$        $f = 120$

$$n_s = \frac{120f}{P} = \frac{120(60)}{4} = 1800 \text{ rpm}$$

$$n_f = 1746 \text{ rpm}$$

$$s_f = \frac{n_s - n_f}{n_s} = \frac{1800 - 1746}{1800} = 0.03 \text{ pu} = 3\%$$

$$(a) \quad T_f = \frac{2T_{max}}{\frac{s_{max}}{s_f} + \frac{s_f}{s_{max}}} \quad \text{as } T_{max} = 200\% = 2 P_u$$

$$1 = \frac{2(2)}{\frac{s_{max}}{0.03} + \frac{0.03}{s_{max}}}$$

$$\frac{s_{max}}{0.03} + \frac{0.03}{s_{max}} = 4$$

$$s_{max}^2 + 9 \times 10^{-4} = 0.12 s_{max}$$

$$s_{max}^2 - 0.12 s_{max} + 9 \times 10^{-4} = 0$$

$$s_{max} = 0.112 \quad s_{max} = 0.008$$

Accept

refused

because  $s_{max}$  must greater than  $s_f$

$$n_{max} = n_s(1-s) = 1800(1-0.112) = 1598.4 \text{ rpm}$$

$$(b) T_{st} = \frac{2 T_{max}}{\frac{S_{max}}{S_{st}} + \frac{S_{st}}{S_{max}}}$$

$$= \frac{4}{\frac{0.112}{1} + \frac{1}{0.112}} = 0.4425 P_u$$

N.m.  $\frac{1000}{1000}$

مقدار تorsi در 1 دای

(مقدار تorsi Reference)

مقدار تorsi در 1 دای

N.m.  $\frac{1000}{1000}$

Td مقدار تorsi در 1 دای

at  $P_f = 0$   $\frac{2}{2}$

$$\therefore P_m = P_o + P_f$$

$$\therefore P_m = P_o = 50 \text{ hp}$$

$$= 50 \times 746 = 37300 \text{ N.m}$$

$$\therefore P_o = T_d \omega$$

$$\therefore \omega = \frac{2\pi \cdot 1746}{60} = 182.84$$

$$T_d = \frac{P_o}{\omega} = \frac{37300}{182.84} = 204 \text{ N.m}$$

$$\therefore T_m = 2 T_d = 408 \text{ N.m}$$

$$T_{st} = 0.4425 (204) = 90.27 \text{ N.m}$$

(3) Ratio to produce Max torque at st. to-

$$R_{act} = \frac{S_1 S_2 R_2}{S_1} = \frac{1 - 0.112 (0.1)}{0.112} = 0.793$$